Enchancing the Energy Performance of Buildings Using Phase Change Material

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Abstract — Buildings and the whole built environment are in a key role when societies are subjected to climate change and adapting to its consequences. Building Construction remains one of the most significant areas of human activities globally. Due to the urgency of measures related to climate change and the need to provide a proper environment for living and working, a large number of energy efficient measures have been agreed to guarantee the future development of sustainable built environment for all. Phase Change Materials (PCMs) are the materials that could initially resist the heat flow and beyond the fusion temperature it stores a large amount of energy in the form of latent heat at a constant temperature without any fluctuations or variations in the temperature. This property of the PCMs finds its usage in many fields conserving energy to a greater extent. The main consideration was made on the regulation of inner temperature fluctuations along with the maximum energy of solar radiation that could be stored and retrieved later. The present project work aims to study the effectiveness of phase change materials (PCMs) in building walls. For preliminary study the Ordinary masonry wall of 3.5 m length and 3 m height was modeled and analyzed in ANSYS and the comparisons were made in terms of Heat flow, Heat flux and Thermal gradient in comparative to the PCM walls. It is noticed that the walls made with PCM materials behaved well in comparison to ordinary masonry wall.

***Key words*: PCM, latent heat, sensible heat.**

I. INTRODUCTION

In the world where there is a continuous increase in the emission of greenhouse gases into the atmosphere and increase in global temperature exponentially it is necessary to use technologies to find a way to reduce the temperature of the buildings inside. Phase Change Materials (PCMs) or latent heat storage materials are suggested to be used along with the insulators in the building construction to reduce the inflow of heat into the building.

Thus it stores a large amount of energy at a given temperature corresponding to the melting point of the PCM by the conversion of its phase. It has a large amount latent heat storage capacity in it when compared to the available sensible heat storage (SHS) material. In general latent heat storage materials are based on the heat absorption or release when a storage material undergoes a phase change from solid to liquid or vice versa.

The PCMs to be used should have thermal properties including suitable phase-transition temperature, High latent heat of transition, good heat transfer and other properties including small volume change, low vapor pressure etc. The phase change materials are classified into three categories namely organic, in-organic and eutectic. Depending upon the application and the properties required, the PCMs are chosen accordingly as hydrates and metallic compounds.

II. BACKGROUND STUDY

Gutherz and Schiler (1991) incorporated a PCM in the ceiling of the building and directed the solar radiation into the PCM so that it heats up and stores the energy of the sun and then releases the heat into the room to keep the room warm enough in the comfort region. They theoretically determined solar areas on the phase change panel coupled with solar radiation data for the city of Montreal, Quebec, were used to determine the amount of solar energy available for passive storage for each daylight hour of a typical day of each winter month (Oct-Mar). Simulation included balancing solar and internal gains against losses and estimating life cycle cost benefits. The three configurations modeled showed a recovery of 17%, 28%, and 36%, respectively.

Athienities and Chen (2000) investigated the transient heat transfer in the floor heating system and focused on the influence of cover layer and incident solar radiation on floor temperature distribution. The study focused on the influence of the cover layer and incident solar radiation on floor temperature distribution and on energy consumption. Complete and partial (area) carpets were considered as well as hardwood cover layers over concrete or gypcrete thermal storage. Experimental and simulation results for an outdoor test room reveal that solar beam radiation can cause a local floor surface temperature in the illuminated area 88^{o}C higher than that in the shaded area. Partial carpet cover further increases floor surface temperature differences up to 158^{o}C when solar radiation is absorbed. Solar radiation stored in the floor thermal mass was found to reduce heating energy consumption significantly (30% or more). Increase of thermal mass thickness from 5 cm to 10 cm did not lead to higher energy savings with conventional proportional-integral control. A detailed study of solar radiation effects on floor heating systems was presented. A three dimensional explicit finite differential model was employed to determine the temperature distribution for a floor with radiant heating and non-uniform solar radiation incident on it. Results from both experimental data and simulation studies

Bakos (2000) used the thermal mass integrated storage on floor to reduce the peak loads so that the storage of heat energy into the PCM is done during the night time when the electricity charges are low. A specific application is studied for a residence heated using a combined sunspace Trombe–Wall passive system solar system and an electrically heated thermal storage floor to satisfy the heating requirements of the house. The mathematical model of the general solution is derived. He used a control strategy, known as maximum principle technique which is also referred to as the quadratic objective function, will be described and its performance characteristics in a combined sunspace Trombe – Wall passive solar system will be determined.

Frank (2002) developed a ceiling board system using PCM which stores heat in off-peak time and releases during peak times thereby reducing the cost of electricity. Unlike conventional sensible thermal storage methods, Phase Change Materials (PCMs) provide much higher energy storage densities and the heat is stored and released at an almost constant temperature. PCMs can be used for both active and passive space heating and cooling systems. In passive systems, PCMs can be encapsulated in building materials such as concrete, gypsum wallboard, in the ceiling or floor to increase their thermal storage capacity. They can either capture solar energy directly or thermal energy through natural convection.

Increasing the thermal storage capacity of a building can increase human comfort by decreasing the magnitude of internal air temperature swings so that the indoor air temperature is closer to that desired over a longer period of time. Alternatively, a thermal storage unit using PCMs can be used with conventional active space heating and cooling systems to improve the overall thermal efficiency as well as to reduce the peak heating and cooling electrical load. There has been significant research conducted on PCMs for space heating and cooling in buildings. However, at present there are only a small number of demonstration systems in use and limited experimental data from testing PCM in real situations.

Kodo et al (2002) carried out a PCM research on using the PCM for ceiling board. He also examined the peak saving control of air conditioning systems using PCMs for office building ceiling boards, which were enhanced by micro-capsulate PCM. This study examined the effects of a peak shaving control of air conditioning systems using PCM (Phase Change Material) for ceiling boards in an office building. Rock wool PCM ceiling board (PCM ceiling board) was enhanced by adding micro capsulate PCM, with a melting point, of about 25°C, close to room temperature. The load on the air-handling unit (AHU) can be reduced by using the thermal storage of the PCM ceiling board during the peak shaving control period. At the same time, the radiation field in the room can be also improved, due to stabilization of the ceiling board temperature at the PCM melting point. The thermal capacity of the PCM ceiling board was measured by using a small experimental chamber. The thermal capacity of the PCM ceiling board is approximately 663 kJ/m^2, which is 4.9 times that of an ordinary rock wool ceiling board.

The effects of peak shaving control were examined, using PCM ceiling board in the experimental chamber. The maximum thermal load using the PCM ceiling board was 85.2% of that of using rock wool ceiling board. As the maximum thermal load was reduced by 14.8% from the rock wool ceiling board, it can reduce the load on the AHU. However, the integrated thermal load was 5.3% greater than that using the rock wool ceiling board. The transition rate of the thermal load to the night was 25.1%. Discounted nighttime electricity, which is 75% cheaper than daytime electricity, can be used in Japan. The running cost is 91.6% lower than that of using the rock wool ceiling board. From these results, it can be concluded that the PCM ceiling system acts effectively to enable peak shaving control.

Mehling (2002) developed a concept where the PCM shutter was placed outside during the day time, where energy is stored in the shutter and during the night time, when the shutter is closed, heat from the PCM radiates the room.

Zhang et al (2006) demonstrated the performance of a kind of shape-stabilized PCM for Building Energy research. The performance of the PCM was also simulated in the Building Energy, software built via experimentation and evaluated the performance of the PCM via energy saving index (ESI). The ESI is the ratio of a particular material or component's energy saving equivalent (ESE) to the corresponding value of the ideal material or component that can maintain the room at an ideal thermal state in passive mode. The ESE can be used to intuitively evaluate the performance of a component or material from an energy standpoint. It can also be used for the performance evaluation of all types of building components or materials in passive applications. The ESI, which is based on the ESE, can be used to characterize the performance of an actual building component or material from a common standpoint. A kind of shape-stabilized PCM's application performance was estimated using the ESI as the evaluation index. The demonstration results showed that the PCM could improve the indoor thermal comfort degree through lowering the indoor temperature fluctuation and slowing the indoor temperature's decline rate. The simulation results show that the PCM's application performance to a residential room depends on the PCM's location and application season, and the insulation material has a better performance than PCM over an entire year.

The objectives of the present study are (i) to study the effectiveness of Phase Change Materials in the energy performance of buildings; (ii) to identify the suitable method for integration of phase change material into the building and (iii) to asses the suitability of phase change material with respect to the different thermal environments.

III. RESEARCH METHODOLOGY

A sample building model is taken for the analysis of the energy performance using phase change materials. The phase change materials are integrated into the south walls of the building such that their thermal transimivity is reduced such that the internal temperature is reduced which will leads to the less artificial energy consumption. Fig.3.1 shows the representation of the building model. A solid boundary of a building is modelled with the help of ANSYS (ver.14.5) software and it is analysed with the help of ANSYS THERMAL (ver.14.5) software. The various constraints associated with the building model were given as input such that the simulation model created by these softwares should be accurate. The modeling details of both the masonry walls (ordinary wall and PCM wall) is shown from Figure 3.2 to Fig.3.4.

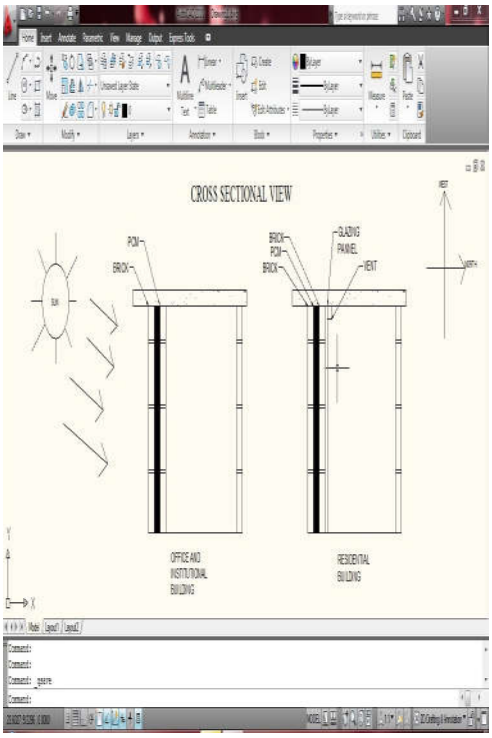

Fig.3.1 Orientation of building model

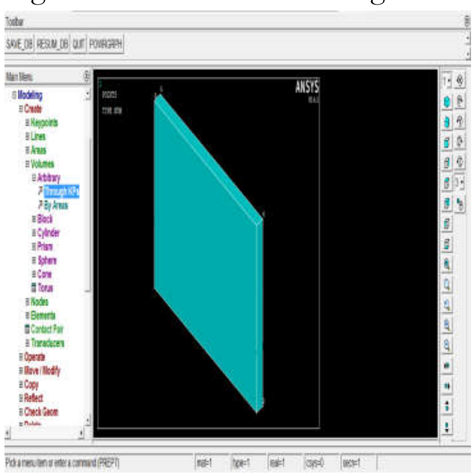

Fig.3.2 Brick wall modeling

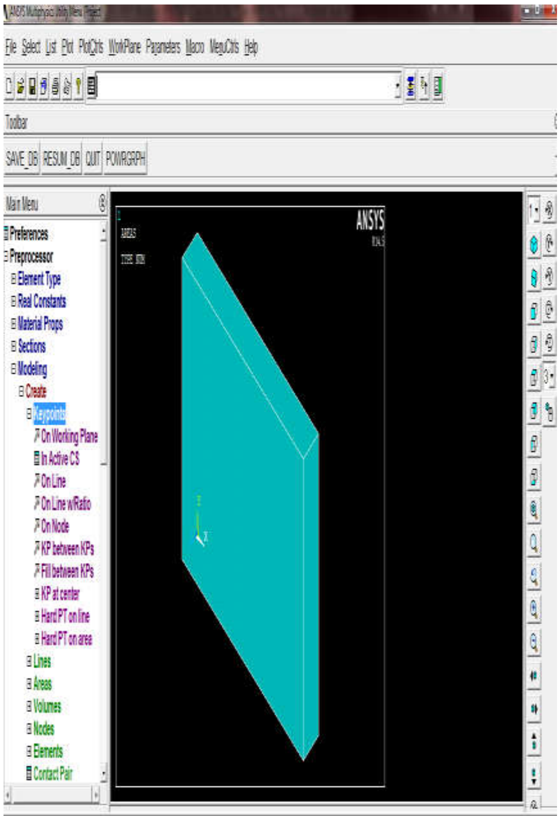

Fig.3.3 Modeling of PCM wall

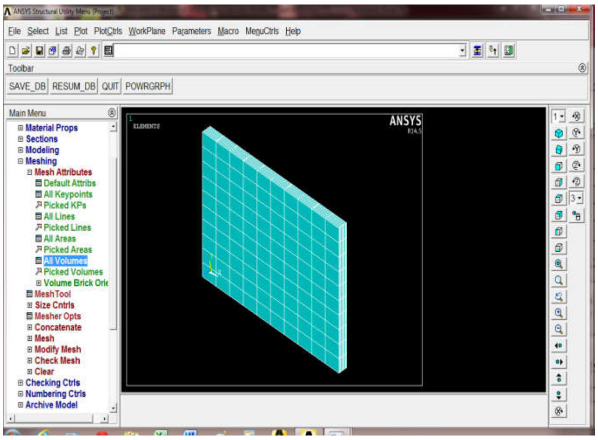

Fig.3.4 Meshing of ordinary wall

IV. RESULTS AND DISCUSSIONS

The results pertaining to the heat flow in ordinary masonry wall and PCM wall are shown in Fig.4.1. and Fig.4.2. It is noticed that the heat flux in ordinary masonry wall is enormous compared to that of Masonry wall with PCM. The heat flux variation in in ordinary masonry wall and PCM wall is shown in Fig.4.3 and 4.4. The thermal gradient of ordinary masonry wall and PCM wall is shown in Fig.4.5 and 4.6 .

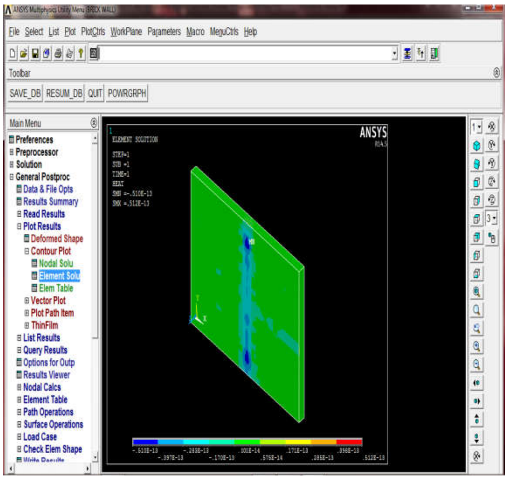

Fig.4.1 Heat flow in masonry wall

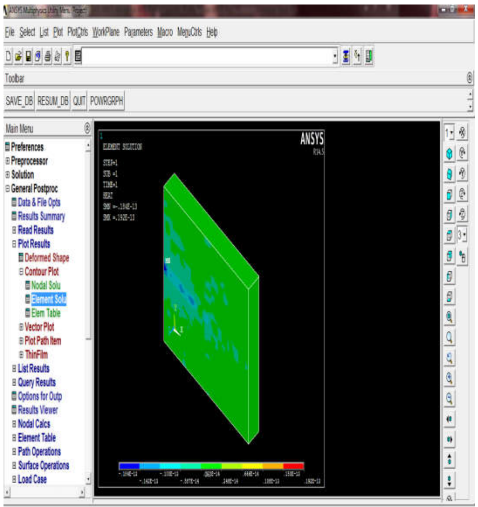

Fig.4.2 Heat flow in PCM wall

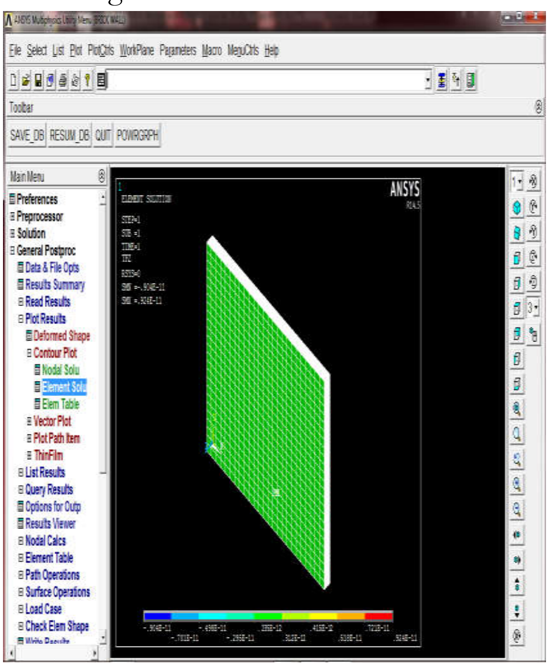

Fig.4.3 Heat flux in masonry wall

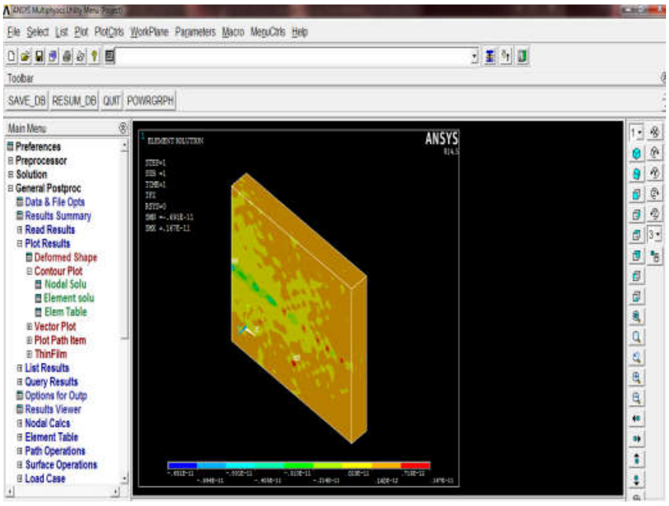

Fig.4.4 Heat flux in PCM wall

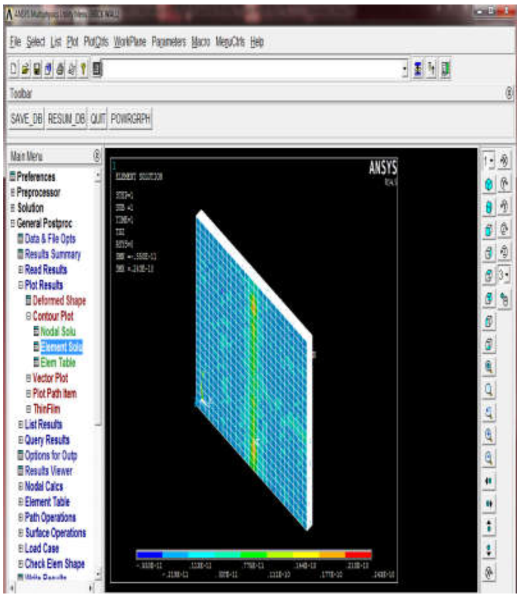

Fig.4.5 Thermal gradient in masonry wall

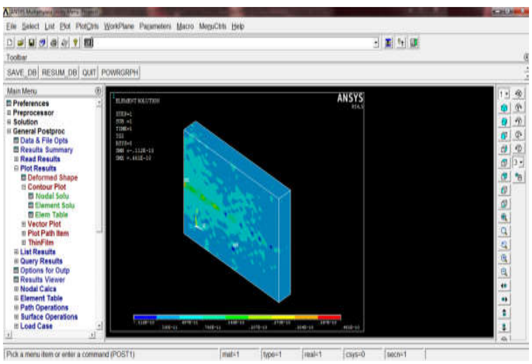

Fig.4.6 Thermal gradient in pcm wall

V. SUMMARY AND CONCLUSIONS

The energy performance of a building can be improved by various method but inorder to overcome the drawbacks created by conventional methods like trombay walls and water walls the PCM incorporated walls are found satisfactory.

A masonry wall is modelled and analysed in ANSYS incorporating ordinary wall and with PCM Material.The thermal characteristics like Heat flow,Heat flux and Thermal gradient are calculated for both ordinary masonry wall and PCM induced masonry wall with the help of Ansys (Thermal software), and it is found that the thermal characteristics like Heat flux,Heat flow and Thermal gradient were considerably decreased from the ordinary masonry wall to the PCM wall.

From the analytical investigatons carried out on masonry wall, the following conclusions were arrrived at.

(i) The heat flow was reduced by 69% compared from the ordinary masonry wall to the Phase Change Material wall.

(ii) Thermal Flux in z axis was reduced by 67% compared from the ordinary masonry wall to the Phase Change Material wall.

(iii) Thermal Gradient in z axis was reduced by 54% compared from the ordinary.

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